Accelerator Science and Technology Centre

Turnaround Feed-Forward correction at the ILC*

A. Kalinin, ASTeC, Daresbury Laboratory, Warrington, WA4 4AD, UK
P. N. Burrows, John Adams Institute for Accelerator Science, Oxford, OX1 3RH, UK

Abstract

The RTML turnaround feed-forward correction scheme, as proposed in the ILC BCD, is considered. Instabilities in the challenging Damping Ring extraction system may give rise to beam transverse bunch-by-bunch jitter, as well as drift across the bunch train. A system is outlined in which the bunch trajectory is measured with an upstream pair of BPMs and corrected with a pair of downstream fast kickers. The beam turnaround time 0.5μs allows signal processing and calculation of the correction. A feed-forward algorithm is formulated and expressions are derived for the main system parameters (BPM resolution, system zero offset stability, kicker voltage, kicker gain compression error) and procedures (matrix measurement, feed-forward gain adjustment). This analysis enables further consideration of the tolerances, and provide a basis for the engineering design.

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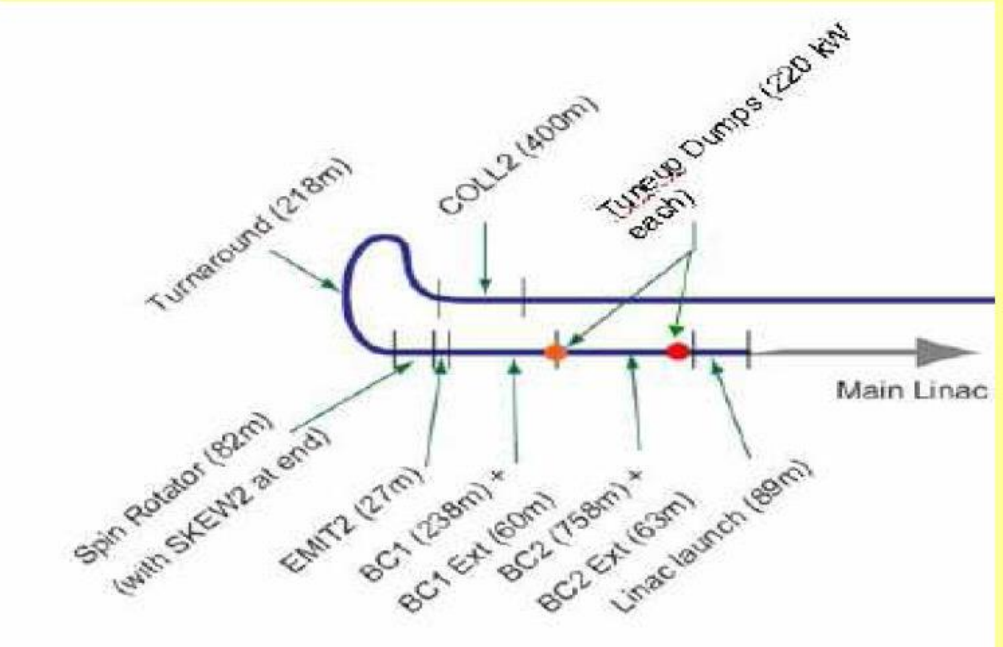
A TURNAROUND AT THE ILC RING-TO-MAIN-LINAC LINE



TOTAL TRAJECTORY VARIATION

- The extracted beam is:

  5Hz-rate 1ms trains of 3(6)MHz-rate bunches
- The trajectory excursion can be characterized through a fast bunch-by-bunch jitter, a drift across a train, and a slow train-by-train drift.
- It is supposed that in the horizontal plane the bunch-by-bunch jitter produced by the extraction kicker exceeds jitter of any other kind.
- Assume that the trajectory rms variation comprising the bunch-by-bunch jitter, any additional jitter, the drift across a train, and the slow drift as well, does not exceed $\sigma_t = \sqrt{2}\sigma$ where **σ** is the bunch-by-bunch jitter rms.
- We assume that the position variations and angle variations are uncorrelated.

CORRECTION RANGE

- The correction range is decided by the requirement on the probability of unsuccessful correction at the ILC. Assume that the number of events beyond the correction range 6 per 1000 bunches is acceptable.
- The (994 per 1000) correction range comes to $\pm 3\sigma_t = \pm 3\sqrt{2}\sigma$. We used this range as the basic range for correction in either plane.
- Assume the kicker jitter $\sigma_{\theta_K} \le 0.5\% = 3\mu\mathrm{rad}$ has been achieved.
- For this jitter, in the septum, $3\sqrt{2}\sigma_{x_K} = 0.63\mathrm{mm}$ that is about

  D=32 times the 1/10 beam size

FEED-FORWARD CORRECTION

- Two BPMs, BPM1 and BPM2, distanced L, in a drift space upstream of the turnaround. The position is x_{BPM1}, the angle is $\theta_{BPM} = (x_{BPM2} - x_{BPM1})/L$.
- Two kickers, K1 and K2, distanced L_K in a drift space downstream of the turnaround.
- The feed-forward correction is:

$$[K_2]\cdot\begin{bmatrix}1 & L_K\\ 0 & 1\end{bmatrix}\cdot[K_1]\cdot[R]\cdot\begin{pmatrix}x_{BPM1}\\ \theta_{BPM}\end{pmatrix} = \begin{pmatrix}0\\ 0\end{pmatrix}$$

  where the transport matrices are in straight brackets.
- The kicks required for correction are calculated using these equations.

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FEED-FORWARD GAIN

- The correction residue is:

$$\begin{pmatrix}\delta x\\ \delta\theta\end{pmatrix} = \left\{\begin{bmatrix}1 & L_K\\ 0 & 1\end{bmatrix} - [G]\right\}\cdot[R]\cdot\begin{pmatrix}x_{BPM1}\\ \theta_{BPM1}\end{pmatrix}$$

  where **[G]** is the feed-forward gain matrix.

- Assume that K1 is distanced from the Extraction Point by a multiple of π/2 which yields $x_{K1}/\alpha_1 \cdot L_K << \theta_{K1}/\alpha_1$ where **α** is the kicker strength. Then the gain acceptable error can be roughly estimated from $|\theta_{K1} - G_{22}\cdot\theta_{K1}| \le |\theta_{K1}|/D$ as

$$|1 - G_{22}| \le 1/D \approx 3\cdot 10^{-2}$$

ACCEPTABLE ERROR OF FEED-FORWARD CORRECTION

- The correction residue propagates to the IP as $\begin{pmatrix}\delta x_{IP}\\ \delta\theta_{IP}\end{pmatrix} = [P]\cdot\begin{pmatrix}\delta x\\ \delta\theta\end{pmatrix}$

  Assume each residue has two independent components: a fast jitter $\tilde{x}$ and a slow drift Δx.
- For both planes the acceptable error of the feed-forward correction can be established as

$$\begin{cases}\sqrt{<\tilde{x}_{IP}^2> + <\Delta x_{IP}^2> + <s_{xIP}^2>} \le \frac{1}{10}\cdot\sigma_{xIP}\\ \sqrt{<\tilde{y}_{IP}^2> + <\Delta y_{IP}^2> + <s_{yIP}^2>} \le \frac{1}{10}\cdot\sigma_{yIP}\end{cases}$$

  where $<s_x^2>$, $<s_y^2>$ are the system noise variances, and σ_{xIP} and σ_{yIP} are the beam sizes at the IP.

MATRIX MEASUREMENT

- The matrix **[R]** and the kicker matrices can be individually measured with the beam, using two pairs of BPMs.
- To obtain a pair of row matrix components, two different trajectories are necessary. To exclude errors from BPM zero offsets, one can use one more reference trajectory.
- As triplets of trajectories, trajectories of three bunches can be used that are different just due to jitter. The matrix elements are averaged over triplets in the train.
- Another variant is to use three train center-of mass trajectories two of which are intentionally perturbed.
- Measurement accuracy is decided mainly by the BPM scale errors.
- The accuracy of the matrix measurement can be evaluated using the fundamental property **det=1**.

FEED-FORWARD GAIN ADJUSTMENT

- In either plane, the gain can be adjusted and monitored using just the beam jitter being corrected.
- The correction residue is measured by the BPM pair downstream of the kickers. To exclude the BPM zero offsets, one can use the differences $Tx_n = x_n - x_{n+1}$, $T\theta_n = \theta_n - \theta_{n+1}$ where n and n+1 are the bunch numbers.
- Assume for simplicity that the matrix **[R]** is errorless.
- Using the correction difference residues

$$\begin{pmatrix}Tx_d\\ T\theta_d\end{pmatrix} = \left\{\begin{bmatrix}1 & L_K\\ 0 & 1\end{bmatrix} - [G]\right\}\cdot[R]\cdot\begin{pmatrix}Tx_{BPM1}\\ T\theta_{BPM1}\end{pmatrix} \equiv Z\cdot\begin{pmatrix}Tx_1\\ T\theta_1\end{pmatrix}$$

  one can calculate four products:

$$\begin{cases}Tx_{1n}\cdot Tx_{dn} = Z_{11}\cdot(Tx_{1n})^2 + Z_{12}\cdot Tx_{1n}\cdot T\theta_{1n}\\ T\theta_{1n}\cdot Tx_{dn} = Z_{11}\cdot Tx_{1n}\cdot T\theta_{1n} + Z_{12}\cdot(T\theta_{1n})^2\end{cases}$$

and a similar pair $Tx_{1n}\cdot T\theta_{dn}$ and $T\theta_{1n}\cdot T\theta_{dn}$ for Z_{21} and Z_{22}.

If for N increasing, each from four correlation series

$$\left(\sum_{n=1}^{N} T_{1n}\cdot T_{dn}\right)\Big/\left(\sum_{n=1}^{N} T_{1n}^2\right)$$

converges to zero or at least to $|\varepsilon| \le 1/D$, the gains are correct. Otherwise change G_{ij} by small increments/decrements until convergence occurs.

SYSTEM PARAMETERS

1. Estimation shows that for the vertical plane the BPM resolution is required **≤1μm**. For the horizontal plane it relaxes to **~10μm.**
2. The long-term system zero offset rms variation should not exceed the BPM rms noise.
3. For the kicker jitter $\sigma_{\theta_K} \le 0.5\% = 3\mu\mathrm{rad}$ the voltage for the $3\sqrt{2}\sigma_{\theta_K}$ kick 13μrad comes to

$$V_{K1max} \approx 3.2\mathrm{kV}$$

4. For a correction with dynamic range D the error due to the kicker amplifier gain compression should be lower than **1/*D***. For ***D*=32** the gain compression is to be

$$a_3 \le 3\cdot 10^{-2}$$

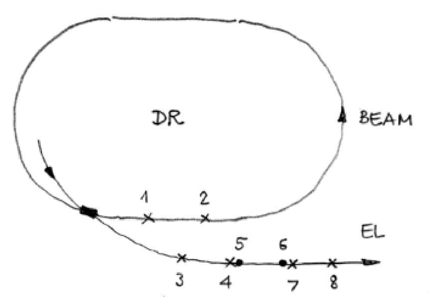
A TURNAROUND FEED-FORWARD CORRECTION PROTOTYPE AT KEK ATF

We propose to build a prototype to the purpose of investigation how far one can advance in accuracy of the ILC Turnaround Feed-Forward correction.

Correction plane: vertical
Turnaround path: last turn in the DR and farther through EL
BPMs: one pair in the DR, three pairs in the EL
Kickers: one pair of strip line kickers in the EL
Beam: two/three 300ns/150ns-spaced bunches
Correction rate: two/three bunch-by-bunch corrections repeated with extraction rate
Feed-forward time: ~0.45μs

PROTOTYPE SET-UP

- **The upstream BPM pair in the DR: 1, 2**
- **The Kickers in the EL: 5, 6**
- **BPM pairs for matrix measurements: 1, 2 and 4, 7 3, 4 and 7, 8**
- **A BPM pair for feed-forward gain adjustment: 7, 8**
- **A BPM pair for excluding the ATF extraction kicker jitter: 3, 4**



ILC jitter is modelled using some set of standing betatron waves excited in the DR with its orbit correctors. On the last turn the particular wave propagates to the EL where it is corrected with the kickers. The correction residue is measured with the downstream BPM pair.

OUTLOOK

- The ILC Turnaround Feed-Forward correction has been briefly considered and its basic features and parameters have been discussed. Some details can be found in [3].
- The correction system looks feasible but raises the engineering challenges. In particular, it is necessary to develop a fast bipolar linear amplifier in the kilovolt range, that delivers tens of kW of power in 1ms. Another challenge is to achieve sub-micron resolution and zero offset drift in a low latency single bunch BPM.
- In advance of the ILC, tests of the solutions, elements, algorithms and procedures of the system could be done at the KEK ATF. Here a path on the last turn in the Damping Ring and further in the Extraction Line can be used to model the ILC turnaround. [4]

ACKNOWLEGEMENTS

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REFERENCES

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